AD-771 017

INTERNATIONAL SHOCK TUBE SYMPOSIUM (9TH) HELD AT STANFORD UNIVERSITY, STANFORD, CALIFORNIA, ON JULY 16-19, 1973

Daniel Bershader, et al

Stanford University

Prepared for:

Air Force Office of Scientific Research
National Aeronautics and Space Administration

5 November 1973

AFOSR - TR - 73 - 2138

Department of AERONAUTICS and ASTRONAUTICS
STANFORD UNIVERSITY

AD 771017

FINAL TECHNICAL REPORT
ON THE
NINTH INTERNATIONAL SHOCK TUBE SYMPOSIUM
HELD AT
STANFORD UNIVERSITY
STANFORD, CALIFORNIA
July 16-19, 1973

Submitted to

Air Force Office of Scientific Research
Contract No. AFOSR 72-2415

Daniel Bershader and Wayland Griffith, Co-Chairmen

November 5, 1973

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR - TR - 73 - 2138	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) NINTH INTERNATIONAL SHOCK TUBE SYMPOSIUM		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) DANIEL BERSHADER, WAYLAND GRIFFITH		8. CONTRACT OR GRANT NUMBER(s) AFOSR 72-2415
9. PERFORMING ORGANIZATION NAME AND ADDRESS STANFORD UNIVERSITY DEPARTMENT OF AERONAUTICS & ASTRONAUTICS STANFORD, CALIFORNIA 94305		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 61102F 9781-02 681307
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Office of Scientific Research/NA 1400 Wilson Boulevard Arlington, VA 22209		12. REPORT DATE 5 Nov 1973
		13. NUMBER OF PAGES ~~25~~ 23
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCL/UNCL
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

PROCEEDINGS

International Shock Tube Symposium 9th Stanford California 16-19 July 1973 pp1-23 1973

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

SHOCK TUBE
SHOCK WAVES
SHOCK ATTENUATION
SHOCK STRUCTURE
LUDWIEG TUBES
GAS DYNAMIC LASERS
SONIC BOOM

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Ninth Shock Tube Symposium was held 16-19 July 1973 in Stanford, California. Sponsored by the U.S. Air Force Office of Scientific Research, Stanford University, NASA, and several private organizations, the meeting attracted around 230 registrants from some 18 countries. A series of 10 technical sessions provided for the presentation of two principal invited lectures, seven additional invited lectures, and 67 contributed papers, selected from a considerably larger number of submissions. Special features of the meeting were the four "brainstorming" conferences and the visit to the

NASA-Ames Research Center. The complete proceedings, edited by the authors of this report under the title Recent Developments in Shock Tube Research, have been published by the Stanford University Press as an 830-page book.

TABLE OF CONTENTS

REPORT ON THE NINTH INTERNATIONAL SHOCK TUBE SYMPOSIUM

by Daniel Bershader and Wayland C. Griffith

Abstract-Summary

The Ninth Shock Tube Symposium was held 16-19 July 1973 in Stanford, California. Sponsored by the U.S. Air Force Office of Scientific Research, Stanford University, NASA, and several private organizations, the meeting attracted around 230 registrants from some 18 countries. A series of 10 technical sessions provided for the presentation of two principal invited lectures, seven additional invited lectures, and sixty-seven contributed papers, selected from a considerably larger number of submissions. Special features of the meeting were the four "brainstorming" conferences and the visit to the NASA-Ames Research Center. The complete proceedings, edited by the authors of this report under the title Recent Developments in Shock Tube Research, have been published by the Stanford University Press as an 830-page book.

Background

An international symposium having as its central theme the use of an experimental device is somewhat unusual, especially when the device is nearing its 75th year of existence. The shock tube, however, is the basic experimental tool for gas dynamics research, much as the wind tunnel is for aerodynamics or the particle accelerator for that branch of physics. Its beautiful simplicity has permitted investigation of a broad spectrum of problems to the extent that shock tube research has provided a unifying influence for the interaction and exchange of ideas among many scientists and research engineers all over the world. The biennial international shock tube symposium is now well established as the principal vehicle for reporting developments in the field, and for the testing of new ideas.

Although shock tube research can be traced back to the pioneering work of Paul Vieille at the close of the last century, it is only during the past 30 years or so that this field of study has taken its place as an important contributor to progress in the physical sciences. The shock tube symposia began as specialists' meetings involving only U.S. researchers in 1957. The first symposium on an international scale was held in Freiburg, Germany in 1967, in memory of the famous German experimental gas dynamicist Dr. H. Schardin. Subsequent international meetings, both highly successful, were held in Toronto, Canada and London, England prior to the most recent one at Stanford. The Tenth International Symposium is scheduled for July 1975 and will take place in Kyoto, Japan. There is every reason to believe that future meetings will continue to attract much interest, because the basic simplicity of the shock tube device, already mentioned, implies an inherent flexibility which permits applications to newer areas of interest as older subjects phase out. Such diverse subjects as astrophysics, acoustics, energy conversion involving gas dynamics processes, environmental problems dealing with chemistry and fluid mechanics, and control of fusion are all receiving attention on the part of shock tube investigators these days. It should be noted as well that shock waves are non-linear phenomena, where physics and mathematics are more difficult and new understanding based on shock tube experimentation is especially rewarding.

Summary of the Program

The opening paper was by Hans W. Liepmann who delivered the Paul Vieille invited lecture. He described his recent work on shock waves in liquid helium using a cryogenically cooled shock tube. At very low temperatures, say around 2 degrees Kelvin, shock heating of the downstream gas always leads to a final thermodynamic state meeting all the criteria of an ideal gas, even for shock waves up to Mach 35! This behavior suggests some interesting experiments at high Reynolds and Mach number, e.g., boundary layer transition studies with highly cooled walls. In another experiment, Liepmann observed the interaction of a shock wave at the interface between helium gas and liquid helium. His data show quite plainly the two transmitted shocks, namely the fast pressure shock and the slow temperature shock. The same experiment carried out at a temperature above the lambda point results in only one transmitted shock. Liepmann described several other interesting results and possibilities for future research.

As part of the endorsement of the meeting by the American Physical Society Division of Fluid Dynamics, a second principal invited lecture was presented by A. G. Gaydon, F.R.S. This was the Otto Laporte Memorial Lectureship for which Professor Gaydon was a good choice since his well-known research in spectroscopy and molecular kinetics of shock heated gases very much overlapped the interests and work of Laporte and his group at the University of Michigan for many years. Gaydon reviewed the history of making temperature measurements by use of light emission with special application to the behavior of the non-linear regime in argon energized by an ionizing shock wave. A comprehensive discussion was presented on how the results of specialized experimental techniques have yielded information on complex processes such as precursor ionization and atomic collision kinetics.

Additional invited lectures were presented by B. Sturtevant on studies of shock focusing and non-linear resonance in shock tubes; J. P. Hodgson on the structure of weak shock waves in mixtures of vibrationally relaxing gases; C. F. Hansen on gas lasers and applications; R. M. Hobson on the shock tube in studies of ionization, recombination and other collision phenomena; R. A. Gross on shock wave heating to fusion temperatures; G. Kamimoto on recent shock tube and related work in Japan; and H. O. Amann and H. Reichenbach on unsteady flow phenomena in shock tube nozzles. Any attempt to give even a moderately complete summary of these interesting papers would be outside the scope of the present report. However, we may mention a few highlights in what follows.

In his experiments, Sturevant was able to observe modification of the behavior of reflected and diffracted wave fronts which evidently result from non-linear propagation. Some of his results relate to Whitham's theory which predicts that as waves strengthen in the area of focus, converging rays bend away from each other and indeed the curvature of the concave wave fronts overshoots and may become convex. Hodgson summarized earlier results on the structure of weak shock waves in atmospheric air, and pointed out that the vibrational specific heat contributions to the relaxation are sufficient to cause waves of the strength of sonic-bang shock waves to be fully dispersed. He was able to generate fully dispersed waves in a shock tube and to observe their structure and compare with theory. Dealing with the same general problem area but concentrating more specifically on mechanisms of individual particle collisions, the paper by Hobson discribed shock tube techniques for the measurement of diatomic ion-electron dissociative recombination coefficients over a wide range of temperatures under highly defined operating conditions in the shock tube. Extension of electrostatic double probe technique to measurement of polyatomic ion recombination is described as is a novel particle detector designed to minimize the interference effects of metastable and resonance radiation.

For some time now Gross and his group at Columbia have been continually improving the state of the art of the use of shock wave heating to obtain ultra-high temperatures associated with extreme shock wave velocities in an electromagnetically driven shock tube. His lecture at the symposium reported shock speeds up to 4×10^8 centimeters per second (more than 1% of the speed of light!) and plasma temperatures up to about 2×10^7 degrees Kelvin. The paper dealt with processes occuring under these extreme conditions, including shock wave structure, shock reflection, plasma-wall energy transfer and non-uniformities in the flow. Along with the capability to provide extreme gas velocities and temperatures as discussed by Gross, the paper by Hansen related to the well-known capability of the shock tube and its variations to participate in ultra-high energy or power transfer via the mechanism of gas-laser interactions. Hansen emphasized the special capabilities of flowing gas lasers and reviewed in some detail the future technological capabilities of these devices. The material he presented would indicate that there should be a strong motivation for the further development of high power gas lasers.

A comprehensive review of shock tube activity in Japan was given by G. Kamimoto. His paper was a reminder that the occasional publications one sees by Japanese authors in the shock tube field are only a small indication of the high level of activity in such research in that country. It is estimated that about 250 people are involved in shock-tube programs, and indeed, there was recently formed a new organization called the Shock Tube Research Society of Japan. The areas of activity cover a wide spectrum and include aerodynamics, shock attenuation, boundary layer interactions, shock structure kinetics, rate processes, plasma dynamics, heat transfer and related theoretical and numerical computational problems. We will surely have an opportunity to hear more fully of Japanese progress in these subjects at the Kyoto meeting in 1975.

The study by Amann and Reichenbach deals with a problem area of continuing interest, especially for aerodynamic applications of shock tube devices such as the Ludwieg tube. The authors presented a series of beautiful shadowgraphs illustrating problems connected with the starting processes in shock tunnels. Studies were made of sharp-edged nozzle inlets, transition nozzles and orifice plates. The results obtained should be of wide application to a wide variety of short duration gas flow systems.

The contributed papers were organized into sessions dealing with weak shocks, shock propagation and sonic booms; lasers and kinetics; advanced experimental methods; high temperature shock waves; molecular rate processes; boundary interactions; shock wave interactions; improved energy transfer in shock-tube drivers; shock-induced chemical reactions; and thermal, chemical, radiative and mechanical studies. Several new subject areas, techniques and results were reported. Work was discussed dealing with bioacoustic applications of shock tubes, a high pressure shock-tube driven gas dynamic laser, population inversion by mixing in a shock tube flow, development of unique instrumentation such as a holographic interferometer for shock tube measurements, design of nozzles for shock tunnels and Ludwieg tubes, use of laser absorption and interferometry as measurement techniques, chemical rates associated with various types of reactions such as pyrolysis, radiative relaxation, further analysis of electric-discharge shock tubes, including the c[illegible]ical arc chamber driver, acceleration of micron-size particles in shock tubes and the mechanism of transition from combustion to detonation in coal dust oxidation, light scattering measurements on aerosols, vapor-liquid condensation studies, and shock tube simulation of stagnation conditions on a Jovian atmosphere entry probe.

The four brainstorming sessions mentioned earlier dealt with the problems of energy exchange in shock tube drivers; laser interactions in shock heated gases; molecular rate processes; and future directions of shock tube research, respectively. These took the form of ad hoc round table discussions in individual rooms, with about 10 or 12 persons in each group. No attempt was made to assemble technical summaries of these discussions for presentation in this report. However, all participants felt that the brainstorming sessions did indeed serve a very useful and complementary purpose to the regular sessions of the meeting, and were generally enthusiastic in recommending such group discussions as a component of future meetings.

<u>Further Assessment and Future Directions for Shock Tube Research</u>

The versalitity of the shock tube as a research and engineering device with a broad scope of subject matter coverage is revealed by a cursory examination of the proceedings of this or of any of the preceding shock tube symposia. At the same time, it should also be noted that there are certain fields where the shock tube has become a quasi-permanent tool. Perhaps the principle example here is the application to chemical kinetics. The ability to provide a well-defined starting time at which a known amount of energy is deposited into a gas under very precisely known conditions clearly permits experimentation in that long-lived branch of physical chemistry. Earlier studies dealing with internal excitation, dissociation and ionization are being extended to include chemical reactions with change of phase, with radiative energy transfer, and with special catalytic effects of small amounts of contaminants or specially treated surfaces, to mention a few.

The current concern of our society for the continuing availability of sufficient energy in suitably useful form indicates that shock tube research dealing with energy transfer processes will continue on a very active level. It may be recalled that some of the first studies on the subject of magneto-hydrodynamic energy conversion were performed in shock tubes, as were a series of related problems in plasma physics. With respect to another type of energy, namely that provided by controlled thermonuclear fusion, there appears to be a good possibility that experiments with gases heated by very strong shock waves will give useful information needed by those who are attempting to make that technology useful. Other recent studies have shown that energy injection to a shock tube gas, carefully phased in relation to the unsteady wave processes which take place, may provide energy transfer efficiencies higher than those achieved previously.

In recent years the shock tube has been used to demonstrate the conversion of energy contained in the flowing gas to high power radiant energy. The experiments have led to the development of the so-called gas-dynamic laser, an instrument which can operate at extremely high power levels. In addition to military applications, such lasers may be used for purposes of communications, both terrestrial and extraterrestrial; triggering of other energy transfer processes, such as thermonuclear conversion; improved techniques in the atmospheric sciences, including possibly the study of clear air turbulence and certain types of high altitude atmospheric pollution; as well as biomedical and industrial applications. Although many of the applications will require CW laser performance, a substantial part of the underlying research and development is more efficiently and economically conducted with shock tubes. We should add here that what has just been said about gas-dynamic lasers which make use of non-equilibrium population inversion, typically obtained by rapid expansion of a suitably heated gas, would also be true for chemical lasers which achieve the inversion by populating excited states via chemical reactions.

The use of laser interactions in shock tube studies is not limited to high power laser generation and related energy transfer. Laser studies of shock heated gases are providing more quantitative information on details of molecular and atomic interactions via such techniques as scattering and absorption studies. The use of Thomson scattering to measure electron temperature, and the use of Raman scattering to measure gas temperature and species concentration has opened new research possibilities, for the simple reason that before the advent of laser sources such scattering experiments were extremely difficult to perform because the scattering cross-sections are small. It would appear that Raman scattering studies of species concentration in chemical reactions of the type occuring in combustion and propulsion processes, but under the controlled conditions existing in a shock tube, would be of special interest these days in connection with the current interest in ecological problems relating to engine exhausts.

We expect that there should be a growing interest in the application of the shock tube to aero-acoustics, especially in the area of behavior of intense sounds. It is well known that sounds of sufficient intensity will begin to exhibit nonlinear effects, with the result that information on such important parameters as acoustic impedience, absorption coefficient of various materials and reflection, refraction and diffraction behavior becomes more complex and requires suitable experimentation to accompany theoretical analyses. The conceptually simple experiment of coating the end wall of a shock tube to measure quantitatively the reflected amplitude of weak shocks (but strong sounds!) would indeed yield information on absorption, some of which is not currently available. He[illegible], the extension to bioacoustics may be mentioned in connection with the study of the effect of sounds and weak shocks on small animals under well controlled conditions. The aero-acoustics field also includes the study of sonic booms. There would, for example, appear to be some value in obtaining more information on refraction of weak shocks by temperature gradients established in a shock tube.

Studies of flows and interactions of two or even three phase moving media will continue to generate interest in connection with environmental sciences and industrial applications. Extensions of earlier studies of break-up of droplets by shock waves and impingment of such droplets on surfaces are examples. Effect of soot-containing gases on the strength of shock waves, and effects of waves on condensation of vapors will probably continue to be of interest in certain laboratories.

The use of the shock tube as a basic research tool should not be forgotten in a discussion of all the applications. For example, the ability to produce a known population of a gas in an excited state under equilibrium conditions makes possible controlled studies of absorption coefficients, f-numbers and related atomic data. Indeed, the well-defined excitation of a gas by shock tube techniques can produce a correspondingly well-defined source of radiation which is more useful than other conventional types of light sources for research applications. The capability of the shock tube for radiation research will continue to be of special interest to those atmospheric scientists working in the field of aeronomy and to those especially interested in solar physics and the phenomena which affect energy transfer between the sun and the earth. In turn, research in these areas relates to the problem of energy availability to our society, carrying the implication that the activity in this field will probably increase rather than diminish in the years ahead.

These speculations on the future of shock tube research were made without the aid of the customary crystal ball. However, a special interest in even one area of shock tube research can lead to a greatly increased level of activity in the field, as was the case in the middle 50's with the widespread application of the device to the simulation of stagnation point heating of re-entry vehicles. (We are, in this connection, waiting for someone to perform a shock tube experiment to determine heat transfer during atmospheric penetration by a flying saucer.) In the meantime, we expect that there will be a goodly number of papers submitted for the Kyoto symposium in 1975, at which time there will be another opportunity to assess the future of this subject.

Appendix I

SPONSORS

Air Force Office of Scientific Research
Lockheed Missiles & Space Company, Inc.
NASA, Ames Research Center
McDonnell Douglas Company
Sandia Corporation
Hewlett-Packard
Jet Propulsion Laboratory
Stanford University
United Technology Center, United Aircraft Corporation

EXECUTIVE COMMITTEE

Daniel Bershader
Wayland Griffith
Donald Baganoff
Robert Dannenberg

ADVISORY COMMITTEE

T. V. Bazhenova, USSR
W. Bleakney, USA
E. A. Brun, France
R. Capiaux, USA
L. Z. Dumitrescu, Romania
R. Emrich, USA
C. Ferrari, Italy
R. G. Fowler, USA
A. G. Gaydon, UK
I. I. Glass, Canada
R. Gross, USA
A. Hertzberg, USA
R. Hobson, Canada
N. J. Johannesen, UK
G. Kamimoto, Japan
A. Kantrowitz, USA
A. K. Oppenheim, USA
S. S. Penner, USA
H. Reichenbach, W. Germany
E. L. Resler, Jr., USA
M. Rogers, USA
A. Roshko, USA
F. Schultz-Grunow, W. Germany
J. Rom, Israel
R. J. Sandeman, Australia
Z. I. Slawsky, USA
R. I. Soloukhin, USSR
J. L. Stollery, UK
C. Treanor, USA
J. Valensi, France

PAPERS COMMITTEE

B. Ahlborn
J. P. Appleton
D. N. Bixler
W. H. Christiansen
R. E. Dannenberg, Chairman
R. G. Fowler
S. P. Gill
R. Hanson
J. J. Jones
J. B. Kyser
F. R. Livingston
W. C. Marlow
H. Mirels
R. M. Nerem
S. R. Pate
W. G. Reinecke
C. E. Rogers
K. Scheller
K. P. Schneider
B. Sturtevant
K. J. Touryan
A. D. Wood

Monday Morning
July 16, 1973
Physics Lecture Hall 100

Appendix II – Program

8:00 AM Registration (Early registration Sunday evening, see above)

9:00 Welcoming Remarks

SESSION I

Chairman: R. G. FOWLER
University of Oklahoma, Oklahoma

9:20 The Paul Vielle Lecture: Cryogenic Fluid Mechanics.
H. W. LIEPMANN, California Institute of Technology, California

10:10 Break

10:25 Weak Shocks, Sound Propagation and Sonic Boom

Recent Studies of Shock Focussing and of Non-Linear Resonant Phenomena in a Shock Tube (invited paper). B. STURTEVANT, California Institute of Technology, California

Recent Development in Sonic-Boom Simulation Using Shock Tubes. J. J. GOTTLIEB and I. I. GLASS, University of Toronto, Canada

Experimental Investigation of Sonic Boom Propagation through Variable Flow Fields. W. L. HARRIS, SR., Massachusetts Institute of Technology, Massachusetts; C. W. CRAIG, University of Virginia, Virginia

Shock Tube Application in Bio-Acoustic Research. R. P. HAMERNIK, and D. S. DOSANJH, Syracuse University, New York; D. HENDERSON, State University of New York, New York

The Diffraction of a Plane Shock-Wave Around an Arbitrary Rectilinear Corner. J. H. T. WU, McGill University, Canada; V. A. AKINSETE, University of Lagos, Nigeria

Monday afternoon
July 16, 1973
Physics Lecture Hall 100

SESSION II

Chairman: A HERTZBERG
University of Washington, Washington

1:45 PM Lasers and Kinetics

Monday morning
July 16, 1973
Physics Lecture Hall 100

SESSION II (continued)

The Structure of Weak Shock Waves Dispersed by Vibrational Relaxation (invited paper). J. P. HODGSON University of Manchester, England

Gas Lasers and Applications (invited paper).
C. F. HANSEN, NASA-Ames Research Center, California

A High Pressure Shock Tube Driven Gasdynamic Laser.
E. L. KLOSTERMAN and A. L. HOFFMAN, Mathematical Sciences Northwest, Inc., Washington

Population Inversion by Mixing in a Shock Tube Flow. V. N. GROSHKO, R. I. SOLOUKHIN, and P. WOLANSKI, Institute of Pure and Applied Mech ·ics, USSR

3:35 PM Break

3:45 Gain Measurements of High Temperature CO_2 Laser Mixtures in a Shock Tube Driven Flow. V. BUONADONNA and W. H. CHRISTIANSEN, University of Washington, Washingt· ı

A Study of the Mechanisms in CO_2-N_2 Mixtures Leading to Radiation at 2.7 Micron Wavelength. H. WONG and P. CASSADY, Lockheed Research Laboratories, California

Pyrolysis and Oxidation of Cyanogen Bromide. T. C. CLARK, J. E. DOVE, and M. FINKELMAN, University of Toronto, Canada

Numerical Study of the Vibrational Relaxation and Dissociation of a System of Anharmonic Oscillators Including Multiple Quantum Transitions. H. WENGLE, Technische Universitat München, Germany

Tuesday morning
July 17, 1973
Physics Lecture Hall 130

SESSION III

Chairman: R. G. JAHN
Princeton University, New Jersey

8:30 AM Advanced Experimental Methods

The Shock Tube in Studies of Ionization, Recombination and Other Collision Phenomena (invited paper). R. M. HOBSON, York University, Canada

Measurement of Plasma Temperature and Density Using Laser Absorption. K. W. BILLMAN and J. R. STALLCOP, NASA-Ames Research Center, California

Shock Tube Study of Plasma Alleviation by Oxide Dust. A. MODICA, G. STEPAKOFF, and H. ROSENBAUM, Avco Systems Division, Massachusetts

Staged Nozzles for Shock Tunnels and Ludwieg Tubes. V. R. BUONADONNA, D. A. RUSSELL, University of Washington, Washington; T. G. JONES, Mathematical Sciences Northwest, Inc., Washington

10:05 Break

10:25 Flow Velocity Measurement in Partly Ionized Rarefied Gas. D. KARSTENS, Universität Göttingen, West Germany

Vibrational Relaxation Measurements by the Combined Shock Tube - Laser Induced Fluorescence Technique. J. F. BOTT and N. COHEN, The Aerospace Corporation, California

A Holographic Interferometer for Gas Dynamic Measurements. G. WORTBERG, Technische Hochschule, Germany

F-Electron Detachment Measurements. A. MANDL, Avco Everett Research Laboratory, Massachusetts

The Particle Trajectories in a Two-Dimensional Shock Tube Flow Observed with a Double-Pass Laser Schlieren System. J. M. DEWEY and D. K. WALKER, University of Victoria, Canada

Tuesday afternoon
July 17, 1973
Physics Lecture Hall 100

SESSION IV

Chairman: S. S. PENNER
University of California at San Diego, California

1:45 PM **High Temperature Shock Waves**

Shock Wave Heating to Fusion Temperatures (invited paper).
R. A. GROSS, Columbia University, New York

Additional invited paper — to be announced.

Multi-Step Ionization Relaxation of Argon Behind a Shock Wave.
M. NISHIMURA, K. TESHIMA, and G. KAMIMOTO, Kyoto University, Japan

Radiative Relaxation Behind Strong Shock Waves in Hydrogen-Helium Mixtures. L. P. LEIBOWITZ, W. A. MENARD, and G. H. STICKFORD, Jet Propulsion Laboratory, California

3:35 Break

3:45 Duplication in a Shock Tube of Stagnation Region Conditions on a Jovian Atmosphere-Entry Probe. D. L. COMPTON and D. M. COOPER, NASA-Ames Research Center, California

A Shock Tube Study of Radiation Behind Shock Waves in CO_2 with Application to Venus Entry. J. E. NEALY and K. V. HAGGARD, NASA/Langley Research Center, Virginia

A Shock Tube Determination of the CN Ground State Dissociation Energy and Electronic Transition Moments for the CN Violet and Red Band Systems. J. O. ARNOLD, NASA-Ames Research Center, California; R. W. NICHOLLS, York University, Canada

A Study of Nonequilibrium Ionization Processes Behind Strong Shock Waves in Helium-Hydrogen Mixtures. L. L. PRESLEY, M. W. RUBESIN, and P. D. ROWLEY, NASA-Ames Research Center, California

Wednesday morning
July 18, 1973
Physics Lecture Hall 100

SESSION V

Chairman: F. SCHULTZ-GRÜNOW
Institut Allgemeine Mechanik, Aachen
Ernst Mach Institut, Freiburg, Germany

8:30 AM Review of Current Shock Tube and Related Work in Japan (invited paper). G. KAMIMOTO, Kyoto University, Japan

Generation of Nozzle Flow by Shock Waves (invited paper). H. REICHENBACH, Ernst Mach Institut, Germany

9:40 Break

SESSION VI-A

Chairman: N. JOHANNESEN
University of Manchester, Manchester, England

9:55 Molecular Rate Processes

Studies of Vibration-Rotation Energy Exchange Using Hydrogen and Its Isotopes. C. J. S. M. SIMPSON, J. M. SIMMIE, and P. D. GAIT, The Physical Chemistry Laboratory, England

The Dissociation of Shock-Heated Carbon Monoxide. R. K. HANSON, Stanford University, California

A Study of the Effect of Reactive Atoms on the Rate of Vibrational Relaxation Using a Discharge Flow Shock Tube. G. P. GLASS, Rice University, Texas

Vibrational Relaxation of Carbon Monoxide and Carbon Dioxide by Atomic Oxygen. R. E. CENTER, Avco Everett Research Laboratory, Massachusetts

Rate of the Dissociation of Vibrationally Excited Cyanogen Formed During the Pyrolysis of Cyanogen Bromide. P. KAYES and B. P. LEVITT, Imperial College of Science and Technology, England

Rate Constants Along Shock Wave Profiles in Dissociating Bromine. A. R. BRIENZA and H. B. PALMER, Pennsylvania State University, Pennsylvania

SESSION VI (continued)

Studies on Vibrational Energy Transfer in CO_2. H. MATSUI, Kyoto University, Japan

Wednesday morning
July 18, 1973
Skilling Auditorium

SESSION VI-B

Chairman: M. ROGERS
U. S. Air Force Office of Scientific Research
Washington, D. C.

9:55 AM Boundary Interactions in Shock-Tube Flows

Investigations of Shock Tube Boundary Layers with a Laser Interferometer. G. SMEETS and A. GEORGE, German-French Research Institute, France

Computation of Gas Parameters and Compensation of Attenuation Effects in Real Shock Tube Flows. L. Z. DUMITRESCU, Institute of Fluid Mechanics and Aerospace Constructions, Romania; R. BRUN and J. SIDES, Universite de Provence, France

Relaxation of the Acceleration-Gas Boundary Layer to the Test-Gas Boundary Layer on a Flat Plate in an Expansion Tube. R. N. GUPTA and R. L. TRIMPI, NASA/Langley Research Center, Virginia

An Analysis of Heat Transfer and Shear Stress in the Shock-Induced Laminar Flow on a Splitter Plate. D. E. ABBOTT, Purdue University, Indiana; J. D. A. WALKER, University College London, England; H. T. LIU, AiResearch Company, Arizona

Determining the Operating Time Behind the Reflected Wave in a Shock Tube. T. V. BAZHENOVA, A. V. EREMIN, V. A. KOCHNEV, and L. M. NAI KO, Institute for High Temperatures, USSR

Influence of Non-Centered Wave Geometry on Unsteady Wall Boundary Layer Development. J. G. HALL, State University of New York at Buffalo, New York

Shock Tube Test of Alder-Wainwright Effect. Y. W. KIM and J. E. MATTA, Lehigh University, Pennsylvania

No formal sessions Wednesday afternoon

Thursday morning
July 19, 1973
Physics Lecture Hall 100

SESSION VII-A

Chairman: W. BLEAKNEY
Santa Barbara, California

8:30 AM Shock Wave Interactions

On the Explosive Sensitivity of Condensed-Phase Explosives. A. J. TULIS and T. A. ERIKSON, IIT Research Institute, Illinois

The Formation and Stabilization of Deflagration Wave Around an Obstacle in the Shock Tube Flow. H. KAWADA and S. TAKAHASHI, Tokyo Institute of Technology, Japan

High-Velocity Flows Springing up by Rarefaction of the Shock-Compressed Liquid Gases. V. V. SILVESTROV and V. M. TITOV, Institute of Hydrodynamics, USSR

A Finite Difference Solution for Unsteady Wave Interactions with an Application to the Expansion Tube. K. J. WEILMUENSTER, NASA/Langley Research Center, Virginia

The Diffraction of Obliquely Reflecting Shock Waves. B. W. SKEWS, University of the Witwatersrand, South Africa

10:10 Break

10:25 Influence of Ionization Phenomena on the Interaction of a Shock-Generated Plasma with a Magnetic Field. F. SARDEI, Max-Planck-Institut for Plasmaphysik, West Germany

Penetration of a Magnetic Field Barrier by an Ionizing Shock Wave. W. J. LOUBSKY, S. G. PRAKASH, and D. BERSHADER, Stanford University, California

A Numerical and Experimental Study of the Unsteady Interaction between Shock-Induced Plasma Flow and Strong Transverse Magnetic and Electric Fields. B. FONTAINE, B. FORESTIER, and J. VALENSI, University D'Aix-Marseille, France

Shock Waves as Diagnostic Tools. P. REDFERN, J. D. STRACHAN, B. AHLBORN, and S. MIKOSHIBA, University of British Columbia, Canada

SESSION VII (continued)

Shock Propagation in a Two-Dimensional Symmetric Logarithm Spiral Channel. R. D. ARCHER, University of New South Wales, Australia; J. H. T. WU, McGill University, Canada; S. M. MOLDER, Ryerson Polytechnical Institute, Canada

Thursday morning
July 19, 1973
Skilling Auditorium

SESSION VII-B

Chairman: R. DANNENBERG
NASA-Ames Research Center California

8:30 AM Toward Improved Shock Tube Performance

Shock Heated Argon in 5-15 km/s Range with Conventional Shock Tube. P. VALENTIN and M. PINEGRE, C. E. A. Etablissement T, France

A Study of Piston Driver Shock Tubes Including Dense Gas Effects. G. ROUEL and B. E. RICHARDS, von Karman Institute for Fluid Dynamics, Belgium

A Study of the Increase of Test Gas in Shock Tunnels Obtained with Preheated Driven Tubes. J. B. KYSER and R. S. HICKMAN, McDonnell Douglas Aerophysics Laboratory, California

A Study on a Radially Divergent-Convergent Detonation Wave. K. TERAO and T. SATO, Yokohama National University, Japan

A Composite Model for a Class of Electric-Discharge Shock Tubes. R. ELKINS, AiResearch Company, Arizona; D. BAGANOFF, Stanford University, California

10:10 Break

Toward Understanding the Conical Arc-Driver. F. R. LIVINGSTON and W. A. MENARD, Jet Propulsion Laboratory, California

Development of an Annular Arc Accelerator Shock Tube Driver. L. P. LEIBOWITZ, Jet Propulsion Laboratory, California

Thursday morning
July 19, 1973
Skilling Auditorium

SESSION VIII (continued)

The Attenuation of Shock Waves in Very Long Tubes. N. ZLOCH, Technische Hochschule, Germany

Thursday afternoon
July 19, 1973
Physics Lecture Hall 100

SESSION VIII-A

Chairman: R. CAPIAUX
Lockheed Palo Alto Research Laboratory, California

1:45 PM Shock-Induced Chemical Reactions

Decomposition of Propane Behind Reflected Shocks in a Single Pulse Shock Tube. A. LIFSHITZ, The Hebrew University, Israel; K. SCHELLER, Aerospace Research Laboratories, WPAFB, Ohio; A. BURCAT, Israel Institute of Technology, Israel

Shock Tube Studies of Chemi-Ionization Processes in Hydrocarbon Combustion Systems. T. W. LESTER, D. M. ZALLEN, and S. L. K. WITTIG, Purdue University, Indiana

Light-Scattering Measurements on Aerosols in a Shock Tube. S. C. GRAHAM and J. B. HOMER, Shell Research Ltd., Thornton Research Centre, England

The Mechanism of Transition from Combustion to Detonation in a Mixture of Coal Dust and Gaseous Oxidizer. S. WOJCICKI, Warszawa Technical University, Poland

Methane Chemistry by Infrared Absorption Spectroscopy. J. H. OWEN, and W. C. GARDINER Jr., University of Texas, Texas

The High Temperature Reduction of Sulfur Dioxide by Hydrogen. R. FIFER, R. MOREAU, and S. H. BAUER, Cornell University, New York

Pyrolysis of Nitroalkanes in Shock Waves. K. GLÄNZER and J. TROE, Institut de Chimie Physique de l'Ecole Polytechnique Fédérale de Lausanne, Switzerland

Thursday afternoon
July 19, 1973
Skilling Auditorium

SESSION VIII-B

Chairman: K. TOURYAN
Sandia Laboratories, New Mexico

1:45 PM **Thermal, Chemical, Radiative and Mechanical Studies with Shock Tubes**

Similar Solutions in Vibrational Nonequilibrium Nozzle Flows — A Parametic Study. N. M. REDDY, Indian Institute of Science, India

Effects of Nonequilibrium Phenomena on the Structure of a Strong Normal Shock Wave. M. GERMANO, M. S. OGGIANO, and M. ONORATO, Politecnico di Torino, Italy

Application of a Radiometric Method for the Measurement of Temperature in Self-Absorbing Gases. R. M. NEREM, J. B. BADER, J. B. DANN, and M. A. CULP, Ohio State University, Ohio

Equation of State of a Nonideal Cesium Plasma Based on Shock Tube Experiments. V. E. FORTOV and B. N. LOMAKIN, Institute of Chemical Physics, USSR

Vapor-Liquid Condensation in a Shock Tube. W. R. SMITH, Lehigh University, Pennsylvania

Shock Tube Measurements of Soot Oxidation Rates at Combustion Temperatures and Pressures. C. PARK, NASA-Ames Research Center, California; J. P. APPLETON, Massachusetts Institute of Technology, Massachusetts

Acceleration of Micron-Sized Particles in Shock Tubes. H. D. von STEIN and H. J. PFEIFER, German-French Institute, France

Thursday afternoon
July 19, 1973
Physics Lecture Hall 100

SESSION IX

Chairman: I. I. Glass
University of Toronto, Canada

4:15 PM The Otto Laporte Memorial Lecture: Light Emission from Shock Waves, and Temperature Measurements. A. G. GAYDON, F. R. S., Imperial College of Science and Technology, London, England